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ABSTRACT

As computers are acquired in greater numbers in schools, their impact on the social organization of instruction increasingly becomes an issue for research. Developments in the cognitive science of instruction, drawing on sociohistorical theory, provide researchers with an appropriate theoretical approach to cultural tools and cognitive change, while developments in the technology of computer-supported cooperative work provide researchers with models for organizational impact outside of education. The concept of a formative experiment in which schools are supported in the appropriation of new technology is illustrated by a project that implements local area network technology in an elementary school. The concept of appropriation derived from sociohistorical theory highlights how schools can make use of technology for goals not anticipated by the researcher. (42 references) (Author)

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Opportunities for Research on the Organizational Impact of School Computers

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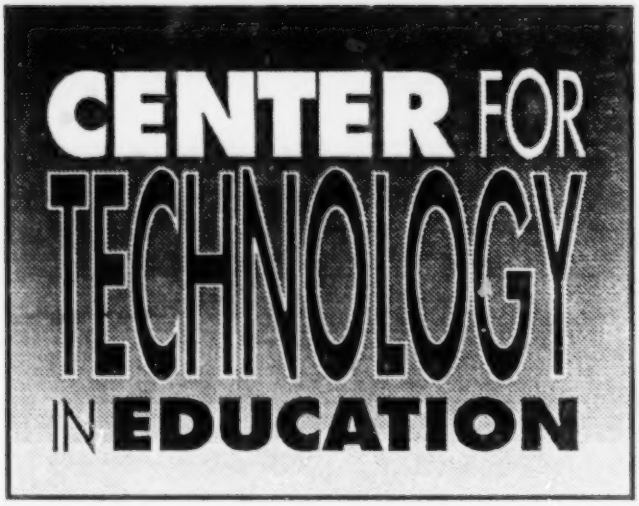

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OPPORTUNITIES FOR RESEARCH ON THE ORGANIZATIONAL IMPACT OF SCHOOL COMPUTERS

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As computers are acquired in greater numbers in schools, their impact on the social organization of instruction increasingly becomes an issue for research. Developments in the cognitive science of instruction, drawing on sociohistorical theory, provide researchers with an appropriate theoretical approach to cultural tools and cognitive change, while developments in the technology of computer-supported cooperative work provide researchers with models for organizational impact outside of education. The concept of a formative experiment in which schools are supported in the appropriation of new technology is illustrated by a project that implements local area network technology in an elementary school. The concept of appropriation derived from sociohistorical theory highlights how schools can make use of technology for goals not anticipated by the researcher.

Researchers have been interested in the impact of computers on the social life of classrooms since the early phases of the introduction of microcomputers (Hawkins, Sheingold, Gearhart, & Berger, 1982; Levin & Kareev, 1980). The Office of Technology Assessment (1985) reports, however, that even with the schools' apparently massive acquisition of microcomputers, there is still an average student-computer ratio of only 30:1, so that computer use is little more than an occasional diversion from the classroom routine With only one computer in a classroom or a small computer lab in the school, teachers are usually able to appropriate the technology into their current practices (Cuban, 1986), but prospects for revolutionary changes in schools resulting from this level of technology are not bright (Cohen, 1988).

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Three factors now present researchers with an opportunity to reexamine the organizational impact of school computers; that is, to observe the ways in which technology reorganizes classroom interactions, provides for collaboration among teachers, and affords new instructional designs.

The first factor is the continued acquisition of computers. If the acquisition of technology continues over the next five years at the same rate as the last five, many schools will begin to have student-computer ratios that make computer use common for routine classroom work over a wide range of the curriculum. Model schools with, for example, 4:1 ratios will be available in sufficient number to form generalizations about organizational impact.

The second factor is the development of a theoretical framework, derived from Vygotsky's (1978, 1986) work, which considers the social environment as an integral part of the process of cognitive change. The framework gives educational researchers a source

of insight into the impact on learning of different ways of organizing instruction. It also gives researchers a methodology for studying the change in complex educational environments through formative experiments on technologies that support different organizations.

The third factor is the technological advances in recent years in computer systems that serve work groups rather than individual workers. For example, local area network (LAN) technology is increasingly common in business and research settings as a means of communicating and sharing data among microcomputers. The introduction of computer-supported cooperative work technology into schools raises important issues concerning the kind of instructional organization the technology will be used to support.

I will illustrate the organizational impact of school technology with a description of a project intended to create an environment for collaborative classroom science investigations. Our interest in the use of technology as a mediator of organizational change derives from the theoretical approach that links the process of learning directly to the kinds of social interactions that constitute instruction. Our interest in the particular technology derives from the current state of the art which, given the growing density of computers in schools, is beginning to offer an opportunity to use technology for changing instructional organization. An outline of the theoretical issues and the technology issues leads us to the methodology of the formative experiment that is illustrated in the last part of this article.

The Sociohistorical Approach to Tools and Change

Recent work in cognitive science that is examining thinking and learning outside of laboratory or school settings (Hutchins, in press; Lave, 1988; Newman, Griffin, & Cole, 1989; Resnick, 1987) has kindled an interest in the developmental theories of Vygotsky, Bruner, and others who have attempted to integrate the internal developmental processes with the cultural artifacts and social processes outside the individual (Bruner, 1966; Laboratory of Comparative Human Cognition, 1983; Rogoff & Lave, 1984; Vygotsky, 1978, 1986). In what is known as the sociohistorical school, cognitive processes involve tools for thinking, such as writing, or computers, that have their own historical development. These tools may be internalized, as with our knowledge of language, or remain external, as with our use of computers. A concept that distinguishes the sociohistorical school from other approaches to development is *appropriation*, a notion introduced by Leont'ev (1981). Learners can appropriate the culture's tools without recapitulating or understanding the process by which the tool was created historically. A tool can, in fact, have quite a different interpretation for the child and the adult. The same object can play different roles in the two systems of activity.

The interpersonal cognitive system is important for understanding cognitive change because (a) culturally elaborated tools play a critical role, and (b) the activities in which the tools function can be conveyed only through apprenticeship. Vygotsky (1978,1986) introduced the concept of a zone of proximal development (ZPD) in which children, with help from others, could work at problems that were beyond their competence as individuals. The knowledge and skills that become internalized, in this view, are the interactive processes by which the problem had been worked on. Appropriation is an important process in the ZPD, on the part of both the learner and the teacher. Newman, Griffin, and Cole (1989) describe teaching and tutorial sessions in which the teacher appropriates the student's actions into her or his own way of understanding the task. The teacher has to find some way for the student to play at least a minimal role in the accomplishment of the task and give feedback in terms of the expert understanding of the task: what the goal is, what is relevant, why his or her move was not optimal, and so forth. All the student has to do is produce some move that in some way contributes (or can be understood as an attempt to contribute) to the task. Seeing how his or her action is appropriate provides the student with an analysis of task as the teacher understands it. Thus, knowledge is actively constructed in the social interactions where the meaning of an action can be changed retrospectively by the actions of others that follow it (Fox, 1987; Newman & Bruce, 1986).

The concept of appropriation applies also to the educational environment's adoption of technology. The tools are interpreted in terms of the ongoing structure of activities. Although tools can serve to amplify an actor's powers, amplifiers must be understood in terms of the organization of the activity, not just in terms of individual capabilities (Cole & Griffin,

1980; Pea, 1985). Computers amplify a teacher's capacity for a variety of kinds of instruction, not by changing the teacher but by changing the instructional activity from, for example, one in which the teacher presents a book-based lesson to one in which students work at a simulation in small groups. The teacher's goal of conveying an understanding of some physical system is more efficiently achieved through a change in the organization of instruction.

The changes that take place when technology is appropriated by an environment may appear to be minimal if the tool is fit into the existing structure (Cuban, 1986). Mehan (1988), for example, described elementary classrooms that were organized into "centers" that simply made the classroom computer another center. Although the school must appropriate the technology in order to use it at all, under some conditions the school can appropriate a technology that, in turn, helps to change the educational environment. This process may result in a new interpretation of the tool as well as a constructive change in the classroom activity (Bruce & Rubin, in press). The new technologies that are designed for supporting different forms of social organization present an interesting challenge for schools.

Computer-Supported Cooperative Work

The use of computers in research laboratories and business offices involves technology designed to aid in the workplace organization. The fact that there is a domain of research and development concerned with the organization of the computer-mediated environment provides additional incentive to explore the possible parallels with the educational environment. In discussions of computers in education, the term *environment* usually stands for a microworld program that lets the student explore an idealized simulation of a real physical or mathematical system. The term *educational environment*, in contrast, refers to the social world in which any such technology functions. The whole environment can simulate a real social environment, such as a research laboratory or a factory, by using technology in analogous ways. Research on the role of technology in constructing such simulations can draw on practical work in creating real environments.

Over the last few years, researchers and technology developers have established a new domain concerned with what has come to be called *computer-supported cooperative work* (CSCW 86,1986; CSCW 88,1988; Galegher, Kraut, & Egido, in press). The domain includes work on electronic mail, video conferencing, distributed databases, group schedulers, and collaborative hypertext environments. Xerox PARC, for example, has explored a system for supporting collaborative research and writing in a hypertext system (Trigg, Suchman, & Halacz, 1986). The integration of written communication with the structure of research notes provides a important model for LAN-based collaboration. Xerox researchers are also designing a system to support face-to-face design meetings (Stefic, Foster, Bobrow, Kahn, Lanning, & Suchman, 1987). Research in this area necessarily moves beyond testing the human-machine interface because the technology is embedded in the social organization. For example, Engestrom, Engestrom, and Saarelma (1988) describe the changing work assumptions of doctors in a medical clinic in which patient records are made a shared resource through computerization. As Grudin (in press) points out, in the absence of analyses of social change and conflict, many groupware applications fail because the designers are naive about the organizational context, very often ignoring the inconvenience that subordinates must endure for the convenience of supervisors.

In the adult world, computers are commonly used in the context of work where software tools are used to create, analyze, and communicate information. School computer use often follows quite a different model. This is especially true for local area network technology—the core of many computer-supported cooperative work (CSCW) applications—where the connection among school computers is used as a convenient way to deliver software to individual computers. School computer use is often program-based rather than information-based, as in office settings. This orientation is seen clearly in computer-based environments such as integrated learning systems (Office of Technology Assessment, 1988), which provide graded sequences of instructional programs to cover large portions of the curriculum and provide teachers with control and monitoring functions. Likewise, commercially available LAN systems designed for schools present students with a menu of programs to

choose from where the teacher has limited student access to a particular set of programs. In the adult world, in contrast, access to sets of information is of greater importance than access to a wide variety of programs.

The new field of CSCW thus provides both a technology with potential application to schools and a research base, often including ethnographic analyses, which critically assesses the technology in terms of the organization of the work setting. The approach often taken is that any work in which computers are used is organized socially even if the hierarchical relationships might not be cooperative (Bannon & Schmidt, 1989). Thus, CSCW research is helping to conceptualize technology as part of socially organized work activity. Of particular importance are the growing number of studies that analyze workplace learning and organizational change as a result of the introduction of technology.

Formative Experiments on the Educational Environment

The continuing increase in the number of school computers makes their impact on classroom organization of increasing practical concern for educators. Models for how such reorganization might be accomplished technically, along with a theory of cognitive change that includes the social organization of instruction, make experimentation also a practical matter for researchers. The technology for supporting social organization combines with a theory in which learning is social and mediated by technological tools to suggest a methodological approach in which the technology is put to use in actual instruction.

A formative experiment can involve elaborate arrangements for teacher training, curriculum development, and production of classroom materials to create an environment in which students and teachers can confront instructional tasks. Working in real classrooms rather than laboratories is essential because the organizational impact is the topic. But a formative experiment, in the sense used here, provides other advantages over traditional experimentation. In a formative experiment, the researcher sets a pedagogical goal and finds out what it takes in terms of materials, organization, or changes in the technology to reach the goal. Instead of rigidly controlling the treatments and observing differences in the outcome, as in a conventional experiment, formative experiments aim at a particular outcome and observe the process by which the goal is achieved (P. Griffin, personal communication). This format is commonly used in formative evaluation of software (Hawkins & Kurland, 1987) where the designer iteratively improves the product until it is successful in terms of appeal and effectiveness. If the environment rather than the technology is the unit of analysis, changes in the instructional interactions, changes in teacher roles, and other ways that the educational environment is changed are observed. The format of the formative experiment, within the context of a classroom or schoolwide intervention, can be used to examine the interactions among students and teachers within small groups as well as in the larger issues of restructuring. The changes in organization brought on by technological support can be understood also as changes in the support for cognition, that is, as new zones of proximal development that amplify the possibilities for instructional interactions.

Different pedagogical goals will suggest different approaches to large-scale computer use and will require different kinds of technological and other support. A pedagogy emphasizing the acquisition of basic skills suggests the use of an integrated learning system in which skill practice is individualized and sequenced. As Cole and Griffin (1987) report, such systems are increasingly found in schools serving disadvantaged populations where concern for test scores drives the agenda for computers. In contrast, a pedagogy emphasizing apprenticeship as a means of attaining higher cognitive skills and understanding (Collins, Brown, & Newman, 1989; Resnick, 1987) suggests modeling school computer use on adult work activities. Each vision of education includes a unique image of how computers function in the classroom organization. Different kinds of support will be required to create various desired environments. Researchers conducting formative experiments attempting to achieve a particular organizational goal can report the level of effort required to achieve it.

This notion of a formative experiment resembles the way that the ZPD concept is often used in the context of tests of cognitive ability where the amount of help the subject needs to reach a criterion performance provides the measure of the subject's place within the zone. The use of static end point, however, although a necessary part of testing, is not inherent in the ZPD theory (Campione, Brown, Ferrara, & Bryant,

1984). In studying the process of cognitive change through observations of the ZPD interactions, it is equally important to understand where the learners can get a certain amount of help. Not all learners will get as far or go in the same direction; many end points are possible since the learner is also an active appropriator of the tools the teacher provides. That is, learners make use of the culture's tools in their understanding of their own tasks, thus reorganizing and amplifying their own capacities.

Whatever the pedagogical theory motivating the experiment, the outcome to be observed must include how the environment becomes organized differently as it appropriates the technology and other resources. The environment may transcend its initial goals. It may also retain goals and organization in spite of the technology designer's concerted efforts to support alternative models. It will not be possible to impose an entirely foreign model of computer use on the schools. For example, the model of the "hi-tech" office may not transfer to schools well even if the same technology were available, because the task of learning as opposed to performing known functions may require different ways of interacting with the technology and cooperating with peers. In a formative experiment, the researcher can learn much by trying to create a different kind of environment in terms both of the supports required to approach the goal and of the environment's appropriation of that support to go in unanticipated directions.

The study reported in the next section illustrates changes in a traditional educational environment after the introduction of technology modelled on computer use in scientific research. Observations of organizational changes show how a formative experiment must track the way the environment makes use of the intervention.

A Formative Experiment on a School LAN Environment

For the last four years, the Earth Lab project has been designing, implementing, and observing the effects of a LAN system intended to facilitate collaborative work in elementary-school earth science. Our plan was to create a prototype LAN system and demonstrate it in a New York City public school using an earth science curriculum (Newman & Goldman, 1987). The pedagogical rationale was that students should use technology the way real scientists do: to communicate and share data—that is, to collaborate. In this project, we used educational technology specifically to change the educational environment from one that discouraged collaborative work among students to one in which collaborative work was used routinely. The goal of the formative experiment was an increase in the frequency of collaborative work. We were prepared to modify the design of the technology, introduce new software, develop curriculum materials, and conduct staff development workshops as needed.

Developing the Environment

A year-long formative experiment was completed in June 1987. A LAN connected the 25 Apple IIe computers in the school to a hard drive, which allowed for central storage of data, text, and programs. The Bank Street Writer word processing program was enhanced with an electronic mail system (Newman, 1987). The Bank Street Filer was another basic tool that made it possible for students to create databases that could be accessed from any other computer in the school.

Databases were used extensively both inside and outside the earth science curriculum. During the lunch hour, students invented databases of their favorite action figures. In social studies, students researched almanacs and other sources to fill in databases about countries of the world and figures from Black history. In earth science, they examined databases of dinosaur fossils and earthquakes, and created a database of the weather readings that small groups of students collected over a three-month period.

The primary means of supporting collaborative groups was through the management of the data organized by groups and individuals. This was the role of Earth Lab's network interface, which made it easy for individuals or small groups to store and retrieve pertinent data. Students and teachers could be assigned to any number of workspaces. For example, workspaces were set up for pairs of students to work on writing assignments together. Other workspaces served schoolwide clubs, such as the Young Astronauts. Each individual also had a personal workspace. The science teacher, who had the students for two periods a week, divided the class into groups of three or four to conduct investigations in the science lab. The science groups gave themselves names that were used for group workspaces on the network. Students shared different data with other students or groups in the

school. A student may have had data shared with a science group, with a noon-hour club, and with the whole class. It would not have been possible for each student to have data on a floppy disk because the social organization of the data access required that multiple routes be possible into the school's database.

Earth Lab is unique among school networks in its orientation to data rather than to programs. The interface presented lists of projects and work groups to choose from and only then presented a list of programs with which to operate on the data. It also was designed fundamentally for collaboration because data are accessed by groups and the word processor made it as easy to send a file to somebody else as to save it in a group or individual directory.

Observations of Changes in the Environment

Along with the technology, we introduced a year-long earth science curriculum designed in collaboration with the teachers (Brienne & Goldman, 1989). Many of the activities were designed for student communication and collaboration, so we expected those features of Earth Lab to be utilized.

What we observed was both more and less than our initial expectations. There was no radical transformation of the school—the innovation took effect slowly. In several areas, the way the system was used surpassed our initial expectations. The following examples are not intended to provide quantitative evidence of changes but to illustrate the mechanisms by which change can occur with this technology.

Network mediation of teachers' collaboration. Over the year, there was substantial movement toward more small-group work. We found the science groups that originated in the science lab being used by the classroom teachers for a variety of social studies research activities, some of which were unrelated to the earth science curriculum. The network system produced these changes in an unexpected way: It made it possible for all teachers to assign classroom work to the groups created by the science teacher. The science group workspaces were a convenient means of organizing small-group projects in other curriculum areas. The science groups became a resource across the school. There had never been a mechanism by which a social organizational structure created by one teacher in this school could be used by other teachers as a resource for managing instruction (Newman, Goldman, Brienne, Jackson, & Magzamen, 1989).

Coordination of students' science investigations. When a shared database came into play, our application of LAN technology naturally seemed to invite coordination in which students contributed to some larger quest for knowledge, because it was easier to give common access to the same database than to maintain separate copies for each individual or group (Newman, et al., 1989). An example is provided by our weather data collection project. Each small group took turns collecting the data for a different day and contributing to a shared database that was later used to ascertain correlations between the variables, such as pressure and cloudiness. The whole data set became the object of group discussion of relationships that could not be found in the individual contributions. This coordination around a shared database was a new activity structure that emerged with the LAN technology.

Transporting work between contexts. We expected that projects would be started while the class was in the computer lab and continued in the classroom. We found that the students were taking this flexibility another step: We observed two students working together at a classroom computer on individual book reports. They had not finished when it was their class's turn to go to the computer lab. Instead of dropping their work, they brought their notes with them and asked if they could continue their work at a lab computer while the rest of the class worked on other assignments. The students logged on and called up the file on which they had been working. The boundaries between one class period and another became permeable. This permeability was used by the students to pursue their tasks on their own initiative.

Network use for students' own work. Many students used the system extensively for their own work in addition to the work assigned as part of instruction. Students developed a greater sense of ownership of their workspaces than we had anticipated. Some students accumulated hundreds of files in their personal workspaces over the course of the year. Earth Lab was also used for student-initiated collaborative work such as science fair projects, which were a source of great pride for many groups of students. Their appropriation of the technology also was evident in end-of-the-year interviews. For example, one student suggested having workspaces for

which students could determine access privileges, in order to make it easy to gain access to work one student was doing with another student. This was an invention based on a need that arose in personal attempts at collaboration.

Use of electronic mail. The communication system built into the word processor was used extensively for both academic and extracurricular communication (Goldman & Newman, in press). In the earth science curriculum, we developed activities in which the science groups worked on a weekly think-tank question and mailed in their replies, and in which the groups mailed questions about their science studies to the other groups. Beyond these structured activities, the communication system opened additional new channels of communication. For example, students and teachers carried on individual conversations, a format that seldom occurred in the regular classroom. Many students used the system for private social communication, and some students carried on extensive exchanges with other people, including adults over the telecommunications connection (Goldman & Chaiklin, in preparation).

Summary and Next Steps

Common to these observations is the perception that students had a place in the computer system, namely their individual and group workspaces containing their project data, which was not dependent on having an individual computer or being in a particular classroom. Both students and teachers made use of the workspaces as a bridge between school contexts. The extent to which teachers and students appropriated the system into their own work gives us reason to believe that systems like Earth Lab are sustainable in the educational environment. The system that we installed in the school was to some extent modelled on the use of technology in research labs, but the system that emerged had characteristics quite specific to schools; for example, the coordination of small groups, the teacher collaboration, and the use of workspaces rather than personal workstations. Our formative experiment succeeded in using technology to increase the likelihood of collaborative work groups, but we also discovered that a critical function of LAN technology in schools is to make a more seamless connection between school contexts.

The next stage of our work on school LAN environments will be to reformulate the goal of the technology from increasing collaboration to increasing use of projects that cut across the usual curriculum divisions. Such projects, whether individual or collaborative, can break down the usual compartmentalization of the school and give students a sense of place in the educational activities independent of tasks assigned by specific teachers. To support this approach, it will be useful to create tools that will support the students in managing and coordinating their investigations (Newman, 1988). We suspect that the solution to the teachers' difficulties in managing instruction involving collaboration among the students and with fellow teachers is to provide students with tools to assume some of the burden, rather than providing teachers with tools with which to gain greater control. Future iterations of design and formative experimentation will further refine the design and continue to explore the changes that are possible in the school environment.

Conclusions

The formative experiment in one school provides information to guide the further design of school LAN environments. It also illustrates features of a research approach that can take advantage of the opportunities to study the organizational impact of the emerging technology. First, the unit of analysis is the classroom or school; hence, it is necessary to experiment in real settings over a period of time sufficient for the environment to appropriate the technology. Second, the logic of a formative experiment in which the experimenter analyzes the support required to reach an initial goal must allow for the goals to change as the environment appropriates the technology. The technology is treated not as the cause of change, but as something that can be used by the school as well as the researcher to support change. As research turns to more fine-grained analyses of the instructional interactions that constitute these changes, the sociohistorical analysis of classroom learning (Newman, Griffin, & Cole, 1989) provides a link between the school or classroom as the unit of analysis and the teacher-student or peer interaction as the unit of analysis.

Systematic research will be needed to explore the conditions under which a technology system best functions. For example, the ratio of students to computers, the support and training of teachers, the grade level and content of instruction may be important

factors in the success of an environment like Earth Lab. The work undertaken by the Center for Technology in Education (Bank Street College of Education) and the Literacies Institute (Education Development Center) with their collaborators at Bolt Beranek and Newman includes a series of experiments to elucidate how different designs of educational environments contribute to success in terms of learning, cooperation, motivation, and so on (Collins, in press). Collins argues that these investigations can lead to a "design science" that is more akin to aeronautics than to natural science because it will attempt to find out what factors make a difference given specified goals—just as in aeronautics the goal is to discover how different designs contribute to life, drag, and maneuverability. It is essentially a science of the artificial as Simon (1981) describes it.

Earth Lab contributes to the design science several hypotheses concerning variables likely to have an effect, such as student-computer ratio, consistency or portability across classroom/lab contexts, and curriculum activities structures. Although the rationale for the design science is expressed in the language of independent and dependent variables, it deeply involves the issues of classroom organization and support for change in experiments that are formative in character. In practice, tinkering and careful observation of how far the school goes with the support provided replaces the definition of experimental conditions and detailed prespecification of dependent measures.

The current state of the design science of education makes it difficult to specify a priori the goals or objectives of all intervention because we do not know what it is possible to achieve with technology or even what will be necessary in terms of cognitive skills, motivation, or community membership in order to address future needs of society. Research on the organizational impact of school computers can proceed by defining plausible goals for the advanced technology becoming available for schools, but remaining open to the emergence of new goals. The analysis of the intervention can contribute to our understanding of the educational process by clarifying how technology helps sustain zones of proximal development that will support students and teachers in achieving their educational goals.

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